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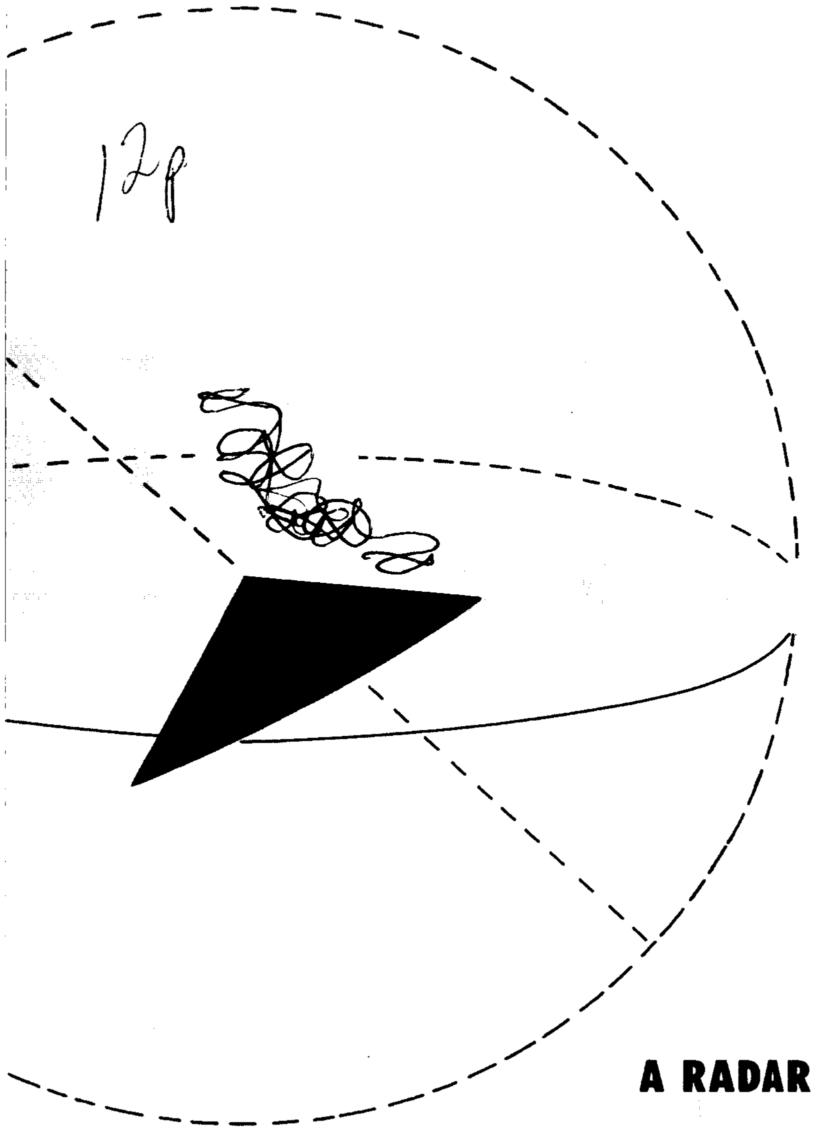

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TRANSLATION NO. 31

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CALIFORNIA INSTITUTE OF TECHNOLOGY

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CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

December 18, 1963

Prepared Under Contract No. NAS 7-100
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TABLE

FIGURES

A RADAR STUDY OF THE PLANET MARS IN THE SOVIET UNION[1]

V. A. Kotelnikov, V. M. Dubrovin, B. A. Dubinskiy, M. D. Kislik,
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A radar study of the planet Mars was conducted during the period of opposition in the first half of February 1963.[2] The 1963 opposition was unfavorable for observation since Mars was at a distance of 100 – 101 million km from the Earth during the time of measurement.

A frequency of approximately 700 Mc was used for the Mars observation, with circular polarization of the radiated signals and linear polarization of the receiver antenna. The overall sensitivity was the same as that in the radar studies of Mercury in 1962 (Ref. 1). The energy of the radiated signal incident on the entire visible surface of Mars amounted to 1.2 w. The transmission was continued for the time period required for the passage of the signal from the Earth to Mars and back (about 11 min); reception was then initiated and continued for the same time period.

The transmitted signal had the form of alternating rectangular pulses and spaces at two frequencies differing by 62.5 cps. The duration of the pulses and the spaces was 4.096 sec at each frequency. The shift of the frequency of the carrier and the keying frequency of the reflected signals caused by the doppler effect was due to the motion of Mars, and the Earth (with account for rotation) was compensated in accordance with a calculated program. The received signals were recorded on magnetic tape, together with a 2000-cps signal serving as a timing scale. The spectral analysis of the received signals on the magnetic tapes was performed just as in the radar studies of Mercury and Venus in 1962 (Ref. 1, 3).

Since the reflected signal was very weak and was impossible to detect in any single test, special attention was devoted to monitoring of proper operation of the entire arrangement.

[1] Translation of *Doklady Akademii Nauk SSSR,* v. 151, no. 4, pp. 811–814, 1963.

[2] The radar study was performed by the Institute of Radar and Electronics of the USSR Academy of Sciences together with several other organizations.

The pointing of the antenna was checked by means of a theodolite mounted on the antenna, with Mars visible at the crosshairs (except for the night of February 9, when Mars was not visible because of cloud cover). Monitoring of the transmitter radiation was accomplished by means of an auxiliary receiver whose output was fed to an oscillograph and into a loudspeaker. Each day before operation began, and again after termination of operation, the sensitivity of the receiving station was calibrated by means of radiation of the extraterrestrial discrete source Cassiopeia A. During intervals between tests the receiver was calibrated on Cassiopeia A.

An electronic frequency meter was used to monitor the correction for the frequency shift caused by the doppler effect. The operation of the modulator could be checked from the photorecordings of the modulating signals which, together with timing marks, were recorded on a galvanometer oscillograph. The complete operation of the setup was verified by use of a simulator which impressed the suitably attenuated transmitter signal on the input of the receiver.

The primary measurements were made every night from February 6-10, 1963. During this period 90 transmit-receive tests were made, each of 22 minutes duration, in which the entire apparatus operated normally. The signal reflected from Mars was reliably detected in 28 tests performed the night of February 7, and in 20 of the tests on the night of February 8.

The results of the analysis of the spectrum of the received signal from the 48 tests in which the reflected signal was detected are presented in Fig. 1. The analysis was performed using filters with a bandwidth of 4 cps; the storage time was 8.5 hr. Δf is the difference in the tuning frequency of the filters relative to the center frequency corresponding to the average calculated frequency of the reflected signal spectrum; W is the energy stored in the band of each filter; σ_W is the rms value of the error of the measurements due to noise. The spectrum of Fig. 1 is the sum of the results of measurements at both frequencies radiated by the transmitter.

As seen from Fig. 1, in the spectrum of the reflected signal a narrow-band component is observed whose energy, accumulated in the center filter band, exceeds by fourfold the rms value of the measurement error due to the noise. There is only a 0.003% probability that this result is due to noise.

In the calculations of the doppler shift of the frequency and the delay of the reflected signals, the value of the astronomical unit A was taken to be 149,599,300 km, which is the value obtained in the radar study of Venus in 1961 (Ref. 2). As seen from Fig. 1, the frequency of the narrow-band component of the reflected signal corresponds to the calculated value (with a maximum error $\delta f = \pm 2$ cps due to the bandwidth of the center frequency filter). Thus, the radar observations of Mars confirm the results of the measurement of the astronomical unit obtained in the radar study of Venus (Ref. 2, 3) and Mercury (Ref. 1). The magnitude of the doppler shift of the frequency caused by the motion of Mars and the Earth during the time of observation amounted to $\Delta f_D = 8 \quad 12$ kc. Therefore, the error in the measurement of the astronomical unit in the radar study of Mars must lie in the limits

$$\delta A = A \frac{\delta f}{\Delta f_D} \simeq \pm 30{,}000 \text{ km} \tag{1}$$

In view of the inadequate level of the signal, a precise measurement of the distance between the Earth and Mars was not made.

The results of the sequential accumulation of the energy of the reflected signals in the 4-cps bandwidth of the center filter during the periods of observation are shown in Fig. 2. The energy accumulation is shown separately for each of the frequencies radiated by the transmitter (curves 1 and 2) and for their sum (curve 3). In the tests conducted on February 7 and 8, when the reflected signal was detected, the energy accumulation was uniform at both frequencies. In the tests on February 6 and 9, when the reflected signal was not detected, the curves oscillate about zero. The cause of the absence of the signal in these tests has not been explained; however, this may be related to a change in the reflective properties of the Martian surface on these days.

For Mars, whose period of rotation (from astronomical observations) is 24 hr 37 min, the total width of the spectrum of the reflected signals at the 700-Mc frequency, accounting for the tilt of the axis of rotation, can attain 2200 cps. The reception of a narrow-band spectrum from a planet with a high rate of rotation indicates the existence on the surface of Mars of fairly smooth horizontal areas with dimensions of several kilometers or more.

The average reflection coefficient of Mars, defined as the ratio of the energy of the reflected signals in a 4-cps bandwidth during the 48 test observations (February 7-9, 1963) to the energy of the signals which would have been received if Mars were a smooth ideally conducting sphere, was found to be 7%. This reflection coefficient is close to the value obtained in the radar studies of Venus and larger than the value for the Moon.

The observed reflected signals came from that portion of the Martian surface which was closest to the Earth at a given instant. As a result of the rotation of Mars the reflecting zone moved almost exactly parallel along the surface during the course of a day (see Fig. 3). From day to day the path of the reflecting zone shifted ~ 500 km in longitude and 7 km in latitude. The area studied was located in the northern hemisphere and had the aerographic (Martian) coordinates: from 14°30′ to 14° latitude, from 310 to 360° longitude, and from 0 to 140° longitude. This area corresponds to the lighter portions of the surface (Fig. 3), which are arbitrarily termed continents.

The longitudinal variation of the reflection coefficient of the investigated areas of the surface of Mars, is presented in Table 1 as determined from the energy of the reflected signals in a 4-cps bandwidth during several test periods.

Table 1. Longitudinal variation of reflection coefficient of investigated areas of Mars surface

Longitude	310 – 320°	320 – 340°	340 – 360°	0 – 20°	20 – 40°	40 – 60°	60 – 80°	80 – 100°	100 – 120°	120 – 140°
Number of test periods	2	2	6	6	5	7	6	6	6	2
Reflection coefficient	13	7	12	7	15	5	3	3	7	3

In view of the small number of test periods, the signal/noise ratio in these measurements did not exceed 1.5 – 2.5, and the data on the reflection coefficient presented in the table cannot be considered very reliable.

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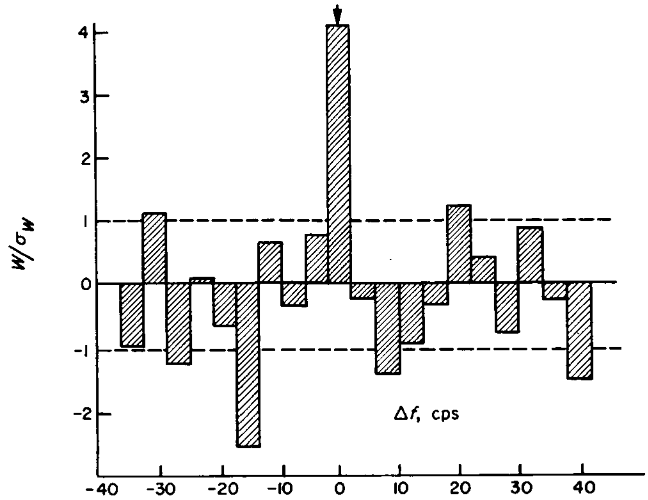

Fig. 1. Spectrum of the received signal

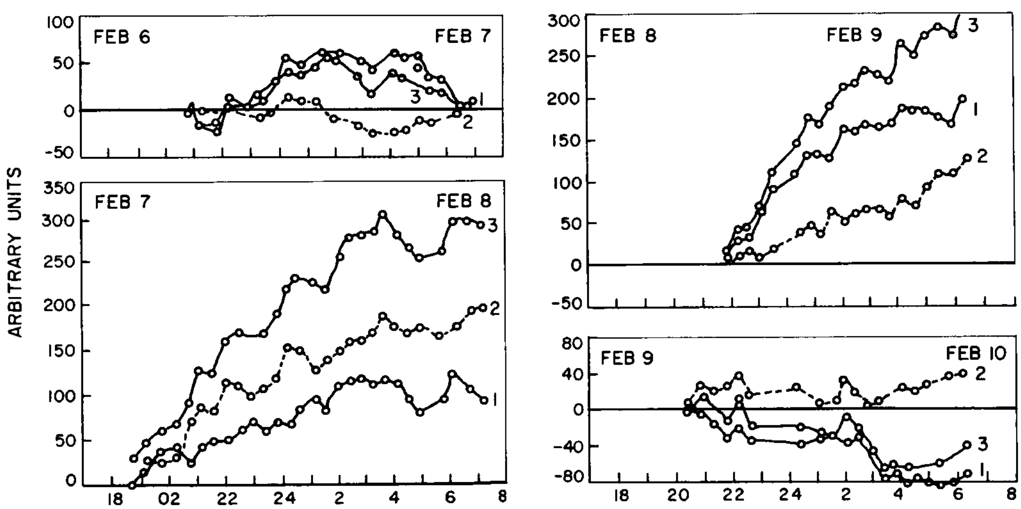

Fig. 2. Results of the sequential accumulation of energy of the signal reflected from Mars in a 4-cps band on February 6--10, 1963

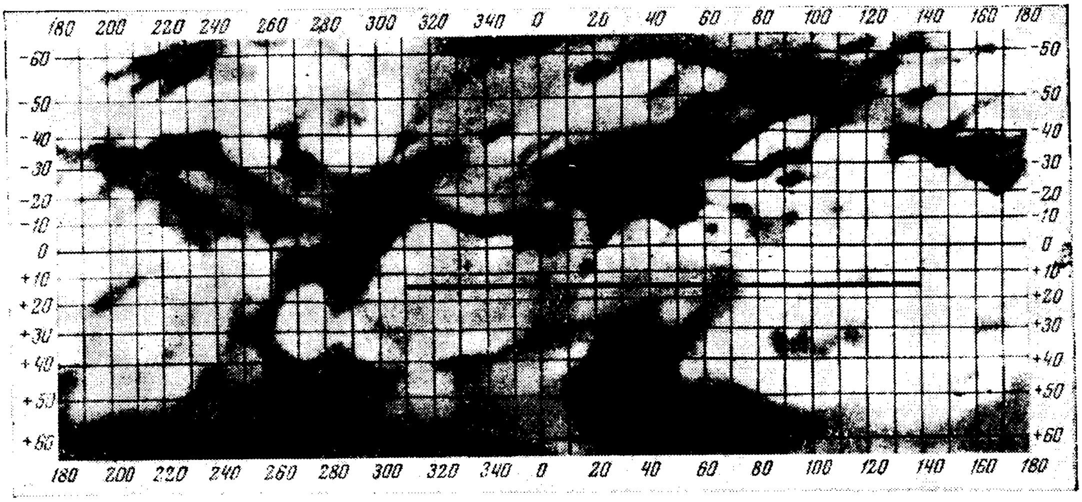

Fig. 3. Astronomical map of Mars adapted by the International Astronomical Congress in 1958 (Ref. 4) showing areas under study